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DOSE ASSESSMENT AT BIKINI ATOLL

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Dose Assessment of Bikini Atoll

W.L. Robison, W.A. Phillips and C.S. Colsher

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was to be a rather large scale effort to sample the soil and vegetation to evaluate the potential dose via the terrestiral pathway. It was felt that this was an especially important goal in view of the significance of the foodchains' contribution to the total dose measured at Enewetak Atoll (1).

For a number of reasons, the scale of the program had to be reduced from that originally planned. The manpower and support were reduced and the aerial survey was deleted, leaving the entire program for measuring the external dose levels on Bikini and Eneu Islands to be accomplished by ground crews (2). The primary emphasis of this reduced effort was toward the external gamma measurements of Bikini and Eneu Islands. Although the sampling of the foodchain pathways was more limited than we had hoped, a smaller scale program designed to help assess the potential dose via ingestion pathways was maintained. The 1975 Bikini survey was finally conducted with the help of 20 people (see acknowledgment) and the support of the ERDA boat - LCU R.V. Liktanur from June 16 through June 24, 1975.

The basic plans for the 1975 Bikini survey are outlined below:

Bikini Soil and Gamma Exposure Rate Survey Program

Purpose: Gamma-Exposure Rate Survey

The gamma-ray exposure measurement program conducted on the ground was designed to provide a detailed examination of the geographical variability of the exposure rates on Bikini and Eneu Islands, and overall verification of exposure rate measurements made during previous visits.

Methods and Measurements

The program utilized the Baird-Atomic scintillation detector which consists of a 2.5-cm-diam x 3.9-cm-long NaI crystal with ratemeter readout.

The instruments were calibrated with a ^{137}Cs point source on the primary calibration range of the National Environmental Research Center, Las Vegas, Nevada. While the response of this instrument is energy-dependent, our experience at Enewetak showed that this was not a serious limitation because of the dominance of ^{137}Cs in the radiation background on the Atoll. We also utilized the Reuter-Stokes high pressure ionization chamber. The current produced by the radiation induced ionization within the chamber is measured by a sensitive electrometer with digital readout. The instrument exhibits a flat energy response over all gamma-ray energies of interest to this survey. It is capable of measuring exposure rates from about 1 μR/hr to 200 μR/hr with an accuracy of about 5%. Thus, the results derived from this instrument were chosen as a reference to which measurements obtained by other techniques were compared.

Measurements of the exposure rate at 1 m above the ground were made with the NaI scintillator at approximately 2500 locations on a 30-m rectangular grid on Bikini Island and at about 120 locations on a 120-m grid on Eneu Island. The ionization chamber was primarily used for measurements within the central section of Bikini Island with additional measurements made at selected areas. Thus, from this program a very comprehensive picture of the gamma-ray exposure rates is available for both islands. Thermoluminescent dosimeters (TLD's) were also employed to supply a third technique for evaluating the external dose. A complete report on the external gamma measurements and resulting dose assessment has been published (2).

Purpose: Soil Survey

The soil sampling program was designed to identify the primary radionuclides contributing to the external gamma exposure and to determine the geographical distribution of these radionuclides in the soil on Bikini and Eneu Islands of the Bikini Atoll. Every possible effort was made to integrate this sampling program with previous programs to avoid undue duplication of effort. The actual number of samples and their specific collection sites were a function of (1) the expected activity levels, (2) future home-construction plans, (3) future agricultural plans, and (4) the number and locations of recent soil samples collected by other programs.

Methods and Measurements

Two types of soil samples were collected for analysis: (1) a 15-cm-deep surface core sample of 60 cm^2 area, and (2) a profile collection based upon sidewall sampling in a trench in which samples of 100 cm^2 area were collected at 15-cm depth increments to a total depth of 90 cm. For purposes of planning the survey, Bikini Island was divided into the north, central, and south sections along the respective second baseline roads. Eneu was divided into the north and south sections divided by the airstrip. The approximate numbers of surface and profile samples collected within these sections are:

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Table A. Number of soil sample locations on each island

	No. of Sample Locations	
	Surface (0-15 cm)	Profiles (0-90 cm)
Bikini		
North of Second Baseline N	25	2
Central Section	200	4
South of Second Baseline S	25	2
Eneu		
North of Airstrip	60	2
South of Airstrip	40	2
TOTAL	350	12 (6 samples each)

Note that a major fraction of the surface samples were to be collected within the central section of Bikini Island. This is due to the relatively higher and more variable gamma exposure rates in this area and to the fact that a major fraction of the returning Bikinians will most liekly reside within this section. A limited number of profile samples were planned in this area because several samples have already been collected during previous surveys. The north and south sections of Bikini Island and all of Eneu exhibit relatively lower contamination levels; hence, the sampling density was lower. Special emphasis, however, was given to the lagoon side of both islands since future homes may also be erected in these areas.

The exact soil sampling locations were actually determined by a random selection process to obtain statistically meaningful and unbiased results. Special samples were also collected within "hot spot" areas or other areas of specialized interest. The samples were placed in plastic bags with appropriate identification tags and readied for shipment to LLL where they underwent preprocessing and gamma-spectral analysis. Plutonium-239, 240 and strontium-90 analyses, were performed by wet chemistry methods at McClellan Laboratory. A complete report on the analytical procedures has been published (3).

Bikini Ground Water Program

Purpose: The ground water program was designed to establish a network of well locations on Bikini and Eneu Islands in order to assess the ground water quality and to systematically study the hydrology and geochemistry of radionuclides, major and trace elements in the ground water system. Water movement and residence times were to be assessed to deduce the transport rates and mechanisms of radionuclides deposited in the soil zone or taken up by vegetation.

Methods and Measurements

Seven holes were drilled with a ground power auger at selected locations along the centerlines of Bikini and Eneu Islands. Pits were dug with a backhoe to a maximum depth since the ground water reservoir surface was approximately 2 meters below the ground surface. The auger penetrated the ground water lens to a depth of approximately 3 to 5 feet. Each hole was cased with slotted 2" diameter PVC pipe which was extended to the soil surface. The pits were backfilled to minimize environmental impact on the area.

The first hole was located near the island center. The salinity of the water was measured with an in-situ conductivity probe. Two holes were then drilled to bracket the center hole and the salinity measured in each.

Water was pumped from the wells, filtered, and sampled. Radionuclides, major elements, nutrients, and bacteria measurements were made at the Lawrence Livermore Laboratory to provide data for water quality. Specific wells were pumped continuously over a day and serially sampled to follow the changes in water quality as a function of usage.

The well network, is available for resampling on subsequent trips we plan to the atoll to thoroughly assess the dynamics of radionuclide cycling in the ground water reservoir and to maintain a surveillance of the water quality. The program operation was fashioned after our Enewetak ground water study and comparison of the data from both atolls should be especially valuable for predicting the mechanism and rates of constituents in ground water at Pacific atolls. A complete report on the Bikini and Eneu ground water sampling and analysis has been published (4).

Plant/Soil Sampling Program

Purpose: The main thrust of the program was to determine radionuclide concentrations in food species; to correlate these with soil concentrations at various depths; to determine nuclide availability to plants in the coral soils; and to relate the radioactivity in food-species to that in indigenous nonfood species which have the potential to serve as indicator species. The unique information that this survey provided is:

1. Soil-to-plant and soil-to-fruit concentration factors for detectable radionuclides.
2. The relationship between food species and nonfood species at the same location.
3. Intra-island variability in vegetation radionuclide concentrations.

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4. A data base for assessment of terrestrial foodchain transfer of radioactivity from the soil to man for long-term dose evaluation upon rehabilitation of the atoll.

Methods and Measurements

The sampling program consisted of integrated sample series of food species and soil profile samples obtained on an ad hoc, species available basis. All food species presently growing and fruiting on Bikini were sampled. A broader sampling program based upon widely available natural species, Messerschmidia and Scaevola, were also carried out to determine the intra-island variations in vegetation radioactivity. Soil profiles were obtained from the root zone of each sampled tree to determine the concentration of radioactivity in the root/soil environment. Both leaves and fruit were sampled so that leaf-to-fruit concentration ratios could be calculated. Nonfood species were sampled in the vicinity of the food species to provide information on species variation in radionuclide uptake, and to evaluate the use of nonfood species concentrations in predictive assessment of human intake when no food products are available for analysis. This approach was developed in the Enewetak survey due to paucity of food species on the atoll. The soil sampling results and the concentration factors and correlation factors developed from the plant/soil data have been published as a separate report (5).

This program along with the ground water program supplies the data base for assessing the long-term dose commitment via foodchains upon rehabitation of the atoll.

Bikini Air Sampling and Resuspension Measurement Program

Due to limited support facilities, manpower, and time, and due to other program demands for air sampling equipment as a result of the delays in fielding the Bikini survey, no attempt was made to establish an air sampling program during this survey.

Sampling Processing

Upon completion of the field survey in June, nearly 1000 samples including soil, vegetation, animals and water were returned to LLL for processing and analysis. Due to funding problems the processing of the samples was not begun until late September; processing was completed by early November of 1975. Sample processing procedures are discussed in detail in reference 3. The time required to analyze this many samples was considerable and had to be incorporated into a priority framework involving other programs. In addition, funding problems prevented analysis of all samples so time was required to establish priorites for which samples should be sent for analysis. As data became available, and as we started our assessment activities, additional samples were identified which were of particular importance for assessment purposes. When limited additional funding became available in the summer of 1976 second priorities samples were sent for analysis and were then incorporated into our assessment activities. Our data bank for the selected samples sent for analysis was finally complete in October of 1976.

Reporting of Results

The results of this survey are presented in a series of reports each dealing with a specific area of interest. It is hoped this will result in

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publications which are easy to use as reference documents. The reports covering the 1975 Bikini Survey are:

1. External Dose Estimates for Future Bikini Atoll Inhabitants, P.H. Gudiksen, T.R. Crites and W.L. Robison, UCRL-51879 Rev. 1 (1976).
2. Analytical Program: 1975 Bikini Radiological Survey, Mark E. Mount, William L. Robison, Stanley E. Thompson, Keith O. Hamby, Austin L. Prindle and Harris B. Levy, UCRL-51879 Part 2 (1976).
3. Evaluation of the Radionuclide Concentrations in Soil and Plants from the 1975 Terrestrial Survey of Bikini and Eneu Islands, C.S. Colsher, W.L. Robison, P.H. Gudiksen, UCRL-51879 Part 3 (1977).
4. Evaluation of Radiological Quality of the Water on Bikini and Eneu Islands in 1975: Dose Assessment Based on Initial Sampling, V.E. Noshkin, W.L. Robison, K.M. Wong, and R.J. Eagle, UCRL-51879 Part 4 (1977).
5. Dose Assessment of Bikini Atoll, W.L. Robison, W.A. Phillips, and C.S. Colsher, UCRL-51879 Part 5 (1977).

B. Living Patterns and Diet

Bikini and Eneu Islands were the two major islands at Bikini Atoll used for residence prior to the evacuation of the Bikini people in 1947. The living patterns adopted for assessment in this report reflect this history and the continuing desire of the people to use these two islands for residence after their return. Since subsistence agriculture will of course occur on the residence islands our assessments reflect both external and ingestion pathway evaluation for these islands. The various possible living patterns toward which we are directing our assessment efforts are listed in Table 1. These living patterns cover a range of possible exposures which could be incurred by a sizeable portion of the returning Bikini population and are the composite of information obtained from the Bikini people, Trust Territory personnel and from experience at Enewetak Atoll.

In addition to living patterns, another major factor in determining the potential dose to the returning population is the assumed diet. A considerable effort was made in the 1972 Enewetak Survey (6) to establish a likely diet for the returning Enewetak population. Based upon those efforts and discussions with the Bikini people, Trust Territory personnel and our observation of the few families presently living on Bikini Island, the diets listed in Table 2 should reflect a reasonable estimate of the potential diet of the returning population.

Two diets are listed: One for 1975 and another for 1980. The difference in the diets reflects our estimates of the availability of certain food products. For example, on Bikini most of the coconut trees are presently not bearing fruit and for the most part coconut fruit availability will be limited throughout the next 5 years. By 1980, however, sufficient coconut will be available so there should be no limitations on dietary intake of coconut due to unavailability. Similarly, Pandanus and breadfruit are not fully matured on Bikini Island and since it will be a few years before these plants are very productive, only a few fruit are occasionally available. Once again by 1980 the availability of both

Pandanus fruit and breadfruit should be sufficient for normal subsistence use. Presently on Eneu Island there are no Pandanus fruit or breadfruit, however, coconut are available. Again by 1980 there should be no limitation on dietary intake of coconut milk or meat due to unavailability. We have also assumed that both Pandanus fruit and breadfruit will be available by 1980 on Eneu.

These dietary estimates are similar to those used in the assessment of Enewetak Atoll (6) and are based upon the research conducted at that time which included discussions with and observations of the Enewetak people living on Ujilang, information from Dr. Jack Tobin, the Marshall Island anthropologist and information from Dr. Mary Murai of the University of California School of Public Health who lived in the Marshall's for several years and has published a book on the Marshallese diet (7). In addition, we have since had the opportunity to observe first hand how both the Enewetak people at Enewetak Atoll and the Bikini people at Bikini Atoll use and take advantage of the available marine and terrestrial resources.

The use of imported foods will surely continue to varying degrees. The extent to which these imports may reduce the daily intake of locally grown food products or locally available marine resources will in turn reduce the dose estimates presented in this report since these estimates are based upon the diets listed in Table 2.

C. Methods of Dose Calculation

The external dose measurements and calculations from gamma emitting radionuclides, primarily ^{137}Cs and ^{60}Co, distributed in the soil on Bikini and Eneu Islands has been described in detail (2).

Previous studies (1, 22) in the Marshall Islands and the analytical data reported here indicate that only ^{60}Co, ^{90}Sr, ^{137}Cs and Plutonium isotopes contribute to the internal dose. The dose calculations resulting from the inhalation and ingestion of these nuclides have been made using the most recent models, transfer coefficients and turnover times available. The dose from ^{60}Co was based upon a single exponential model with a biological half time of 10 days (17). The transfer across the gut to whole body was taken as 0.3. For ^{137}Cs a two component exponential function was used. 100% of the ^{137}Cs ingested is assumed to reach the whole body. Of the total ^{137}Cs reaching the body, 15% has a biological half time of 1 day and 85% has a biological half time of 115 days (8).

The critical organ for ^{90}Sr dose calculations is bone marrow. The doses from ^{90}Sr presented in this report are for bone marrow and are calculated using the method developed by Spiers (9, 10, 11) and used in the UNSCEAR reports (12). This model calculates the dose using a quality factor (QF) of 1 without the use of an "n" factor for non-uniform distribution in the bone (13). Under these conditions the bone marrow doses should be compared to the 0.5 rem per year guide for members of the public rather than the 3 rem per year criteria (14, 15, 16) used if mineral bone doses are calculated using an "n" factor of 5 (13, 17). The bone and liver doses resulting from $^{239,240}Pu$ were calculated using the ICRP lung model (18, 18A) and the most recent paramters for transfer from the lung, across the gut wall and for retention time in the critical organs (18, 19). A summary description of this model and associated transfer and retention coefficients is given in a recent paper by Martin and Bloom (20).

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The effective energies (E) and the fraction ingested reaching the organ of reference (F) for the four radionuclides which produce over 99% of the dose are listed in Table 3.

D. Exposure Pathways: Description and Dose

1. External Gamma

The description of the measurements, dose calculations, and dose estimates for the external exposure pathway have been reported in detail (2). In summary, ^{137}Cs and ^{60}Co produce nearly all the external dose on both Bikini and Eneu Islands with ^{137}Cs contributing approximately 94% of the total. In addition, the dose levels on Eneu Island were found to be less than those on Bikini Island by about a factor of two.

The first year dose and 30 year integral dose for the two islands as a function of the alternative living patterns is shown in Table 4. Integrated external exposures for 10 years, 50 years and 70 years are listed in Tables 27, 29 and 30 respectively. Housing located in the interior of Bikini Island (area 3 in Figure 2) leads to the highest external exposure (Case 5 and Case 6). The annual Federal guide for a member of the population is 0.5 rem for the whole body and 0.5 rem for bone marrow. For Case 5 and 6 the estimated first year dose of 0.28 rem is a considerable fraction of the annual guide and leaves little room for dose accumulation via other pathways. Similarly summing the annual guides for 30 years leads to a 30 year guide of 15 rem and the estimated 30 year integral dose for Case 5 and 6 is 5.9 rem. Again, over a 30 year period, the external dose received from this housing location and living pattern does not allow

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much leeway for exposure from other pathways. This is very significant because potential doses via the terrestrial foodchain can exceed those due to external exposure.

Housing constructed in area 2 (Case 4a, 4b) along the lagoon road reduces the external exposure relative to Case 5 and 6 by approximately 25% depending upon which remedial action is considered. Placing crushed gravel around the houses is commonly done and is easily accomplished. The soil removal and replacement, however, is a more difficult action to implement. Living in residences already established on Bikini Island (Figure 3, are 1 in Figure 2) leads to the smallest external exposure on Bikini Island (Case 2, 3a, 3b); the 30 year doses for these cases range from 4.3 to 4.0 rem. Living patterns on Eneu Island lead to the lowest external exposure doses. The first year dose of 0.12 rem and the integrated 30 year dose of 2.9 rem are nearly a factor of two lower than the Bikini Island options. The Eneu living pattern, therefore, has more flexibility for potential exposure via other pathways without exceeding Federal guides.

2. Inhalation Pathway

No air sampling data was taken during the 1975 Bikini survey. Some open field aerosol measurements have been taken during previous work conducted at Bikini Atoll (21, 22). Because of the sparcity of the data, however, and also because of the lack of data concerning resuspension processes in the atoll environment, the average concentrations of Pu in the soil have been used in a mass loading model to predict the doses via the inhalation pathway. This is the same approach used to evaluate the inhalation pathway at Enewetak Atoll (23).

The mass loading concept may be more relevant for estimating the potential dose via inhalation than open air aerosol measurements because the resuspended material created by a person in his own immediate environment may be significantly greater than is reflected in open air measurements. Therefore, it is assumed that the concentration of Pu observed in the surface soil at Bikini and Eneu Islands will remain the same in the respirable resuspended surface material. In addition, a mass loading of 100 μg per m^3 and a breathing rate of 20 m^3 per day are used to develop the Pu inhalation rate in pCi per day. A mass loading of 100 μg/m^3 is at the high end of the observed range for normal open air aerosol measurements. However, in view of the fact that local resuspension created in the immediate vicinity of an individual during his normal activities is probably greater than open air measurements, it appears reasonable, for lack of specific data, to use the higher number. The average Pu concentrations in the surface soils (0-5 cm) for Bikini and Eneu Islands are 9.3 pCi/g and 1.4 pCi/g respectively. The pCi per day intake resulting from the above model is therefore, 0.019 and 0.0028 for Bikini and Eneu respectively.

The doses resulting from inhalation of $^{239,240}Pu$ are listed in Table 5 for the three critical organs: Lung, bone and liver. The doses predicted for Eneu are of course less than those predicted for Bikini Island.

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These doses will be compared later in this report with bone and whole body doses from other pathways.

The concentration of ^{241}Pu in the soil on Bikini and Eneu is approximately 10 times that of $^{239,240}Pu$ (3). However, due to low energy beta radiation (0.021 mev maximum) and a much shorter half life (14 years) the integrated 30, 50 and 70 year doses from ^{241}Pu are more than an order of magnitude less than those listed in Table 5 for $^{239,240}Pu$.

The observed concentrations (pCi/g) of ^{241}Am in the soil at Bikini and Eneu is approximately one half of the $^{239,240}Pu$ concentrations. However, additional ^{241}Am will result from decay of ^{241}Pu. The parent-daughter relationship for $^{241}Pu/^{241}Am$ is shown in Figure 4. The maximum ^{241}Am activity that can be obtained is 2.6% of the initial ^{241}Pu activity. The present ^{241}Pu soil activity levels are 10 times that of $^{239,240}Pu$. Therefore the final ^{241}Am soil activity resulting from the decay of ^{241}Pu is 0.26 that of $^{239,240}Pu$. The currently observed ^{241}Am soil concentrations are 0.55 that of $^{239,240}Pu$. Thus, the final total soil concentrations of ^{241}Am resulting from ^{241}Am presently observed and that which will grow in from ^{241}Pu will be 0.81 that of the $^{239,240}Pu$ soil concentrations. For estimates of dose via inhalation the eventual ^{241}Am soil concentrations can be considered equal to the $^{239,240}Pu$ concentrations. As a result the doses shown in Table 5 for $^{239,240}Pu$ can essentially be doubled to account for the ^{241}Am.

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3. Drinking Water Pathway

The analysis of the cistern water and ground water have been published in detail in a separate report (4). Both radiological and chemical analyses were performed. A summary of the radiological quality of the water will be presented here. For more detail and for data on the chemical quality, the original report should be consulted.

The data from the cistern water in Bikini Island are given in Table 6. The ground water data from Bikini and Eneu are listed in Table 7. For the alternate living patterns it is assumed that only the cistern water will be used for consumption. Therefore, the dose assessment via this pathway was based upon the average values listed in Table 6. The ground water data is presented to give a comparative picture in the event ground water were used for potable water.

The 10, 30, 50 and 70 year integral doses resulting from the consumption of Bikini cistern water were listed in Table 8 and are of the order of a few millirem for whole body and bone marrow. These are the doses used in the subsequent dose summary tables. The whole body and liver dose is contributed almost entirely by ^{137}Cs. ^{90}Sr and ^{137}Cs are approximately two orders of magnitude more significant than $^{239,240}Pu$ in contributing to bone marrow dose. Table 9 and 10 compare the doses based upon the consumptions of Bikini and Eneu ground water. The 30, 50, and 70 year doses resulting from consumption of Bikini ground water range from 1 to 2 rem for bone marrow and 0.4 to 0.7 rem for whole body. This is a very significant increase over the estimates resulting from consumption of cistern water. The estimates based upon consumption of Eneu ground water also (Table 10) exceed those based upon consumption of cistern water; the 30, 50 and 70 year integral doses range from 0.2 to 0.4 rem for bone marrow and 0.03 to 0.05 rem for whole body. All doses were based upon a daily intake of water of 2 liters.

4. Marine Foodchain

No marine samples were collected during the June 1975 survey. This was the result of both the limited manpower and time available for the survey and the fact that the marine pathway proved to be much less significant than the terrestrial and external gamma pathways at Enewetak (1, 24). From this relative point of view we expected both atolls to be very similar.

The data used, therefore, to evaluate the potential dose via the marine foodchain was obtained from published data (22, 25) and from unpublished data supplied through the courtesy of Dr. Vic Nelson of the Laboratory of Radiation Ecology-University of Washington. Table 11 lists the fish data used for the dose assessment. Table 12 lists the clam data. The average concentration of the radionuclides were determined from the data in Tables 11 and 12 by weighting by sample size and by assuming that detection limit values ("less than" numbers) were actual concentration values. The final concentration values used in conjunction with the 600 g per day intake of fish to calculate the pCi per day intake via the marine foodchain are listed in Table 13.

The species of birds that are readily caught and used as part of the diet are marine feeders, mostly species of terns. Therefore the radionuclide concentrations in their muscle tissue is similar to that in the marine diet. For this reason, birds and bird eggs are considered part of the marine diet for dose calculation purposes. No birds or bird eggs were collected in June of 1975 so the data used to evaluate this part of the marine foodchain comes from previously published reports (22, 26). These data are summarized in Table 14. The final concentration data used for dose assessment, and listed in Table 15, were derived assuming that 6 times more bird muscle is consumed than liver, and that the wet-to-dry ratio is 0.33 for muscle and liver and 0.25 for eggs. Due to the non-existence of Pu concentration data in birds and bird eggs on Bikini, and the similarity of Bikini and Enewetak bird muscle and liver data, the Pu concentration values listed in Table 15 are those from the Enewetak Radiological Survey (27).

The 10, 30, 50 and 70 year integral doses resulting from ingestion of marine foods are given in Table 16. ^{90}Sr contributes the largest fraction of the bone marrow dose (70-80%); ^{137}Cs contributes approximately 20% while ^{60}Co and ^{239,240}Pu contribute about 6% of the total. The whole body dose from the marine pathway in 50 mrem for the integrated 30 year dose and 66 mrem for the 50 year integrated dose. The bone marrow doses are 200 mrem and 290 mrem for the 30 year and 50 year integral doses respectively. These integral doses are small relative to those from other pathways. Although the marine pathway contributes a significant fraction of the total ^{239,240}Pu intake relative to other pathways, the resulting dose compared to ^{90}Sr and ^{137}Cs is very small.

5. Terrestrial Foodchain

The availability of locally grown terrestrial food products was still minimal in June of 1975. Thousands of coconut trees were planted in latter half of 1969 on Bikini and Eneu but only a few were bearing fruit in 1975. Pandanus fruit and breadfruit were planted during the

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same time period on Bikini Island and the first few fruits from these trees have appeared over the past year and a half. The number of these trees is, however, not great and they are not distributed over the entire island. No breadfruit or pandanus fruit have been planted on Eneu. Banana and papaya trees were also being planted at two locations on Bikini Island and have produced fruit over the past two years.

As a result of the sparcity of available food crops, our goals in the limited survey were to sample the vegetation of all species of food crops available as well as indicator plants such as Scaevola and Messerschmidia; to sample edible fruit where available; and to take soil profile samples through the root zones of the sampled trees. From these data, we have developed concentration factors relating concentration in food products to soil concentration, as well as concentration ratios which relate the concentration in the vegetation (leaf) to the concentration in the edible fruit or the concentration in indicator species (Scaevola and Messerschmidia) to concentrations in food crops (5).

A separate report (5) discusses in detail the results of the sampling program and the development of the concentration factor and concentration ratio. In brief, we found the distribution of radionuclides in both the Bikini and Enewetak environments to be very inhomogenous. Radionuclide concentrations in soil were observed to vary greatly over distances of only a few feet. The results of our work during this survey verified our thesis that due to the wide variability in soil concentration with location, useful concentration factors can only be calculated from vegetation and soil data sampled from exactly the same site. Concentration

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factors developed using soil sampled from the root zone of the vegetation under investigation showed a greatly reduced range of values in comparison with values developed earlier from unassociated vegetation and soil samples (28, 29, See also Table 17 this paper).

The concentration factors developed from this survey are more precise and provide a better basis for estimating the average radionuclide concentration which would be expected from crops planted in certain regions within an island or on different islands.

Despite the greater preciseness of concentration factors calculated from associated vegetation and soil data, these values still show some variability. This remaining variability can be accounted for by several factors acting either alone or in concert. These factors include:

1. differences in soil type, organic content and chemical characteristics
2. differences in physiochemical properties of the radionuclides
3. differences in soil management practices
4. differences in irrigation practices
5. differences in the physiology, age and prior history of the sampled plants

One would in fact expect to see some variation in sampling conducted within a specific tree just due to normal biological variability.

In addition to the development of CF, the data from the large surface soil sampling program (5) were used to develop average soil concentrations for four regions on Bikini Island and for the whole of Eneu Island. These average soil concentrations were then used in conjunction with the concentration factors we developed to predict the radionuclide concentrations expected in the terrestrial food products. The results are listed in Table 18.

During the June survey a fully grown pig and two chickens which had been born and raised on Bikini Island were obtained for analysis. The pig and chickens roamed freely around the island so the radionuclide concentrations measured in these animals reflect the integrated diet of the animals. Analysis of these samples serve to determine ingestion via the meat pathway. The estimates for the radionuclide concentration expected in meat on Eneu were determined by multiplying the observed concentrations in the meat samples from Bikini Island by the ratio of the average Eneu-Bikini soil concentrations. Since most of the animal diet consists of vegetation and a certain amount of soil, this ratioing procedure should predict reasonable concentrations for domestic animals raised on Eneu.

Although coconut crabs were not collected during the June 1975 survey they have been collected during previous visits to the islands. As a result, the values listed for coconut crab in Table 18 were determined from data resulting from collections in 1969, 1972, and 1974 (22, 26, 30).

Concentrations in food products for periods after June 1975 are calculated assuming that the only loss of radionuclides from the environment is the result of physical decay of each radionuclide. This conservative approach was adopted because we lack any definitive information which would indicate that environmental processes might result in more rapid effective removal of radionuclides from the environment. As a result, any environmental process which might cause the removal of radionuclides from the environment which is more rapid than the physical decay of the radionuclides would of course reduce the predicted concentrations in the food products and as a result would reduce the predicted doses via the terrestrial pathway.

The dietary intake values listed in Table 2 and the concentrations listed in Table 18 were used to generate the pCi per day intake of each of the radionuclides. The results in Table 19 are for a diet entirely from Eneu Island while those in Table 20 are for a diet originating solely from Bikini Island. Table 21 lists the pCi per day intake for a diet originating from Bikini Island but excluding Pandanus fruit and breadfruit. The contribution from Pandanus fruit and breadfruit originating on Eneu Island were included in the diet for 1980. Table 22 lists the pCi per day intake for a diet which only allows the use of coconut from Bikini Island. In other words, the rest of the diet is from Eneu. The data are used with the various living patterns as follows:

Living Pattern	Intake Data
Case 1	Table 19
Case 2	Table 22
Case 3	Table 21
Case 4	Table 22
Case 5	Table 21
Case 6	Table 20

The data for Bikini Island were broken down by area as shown in Figure 2. However, in view of the fact that subsistence agriculture could come from any one of the four areas and because the results do not differ greatly by area, the average value for the four areas on

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Bikini were used for the dose assessment. Because of the relatively uniform concentration of radionuclides observed on Eneu only one set of intake values was developed based upon the island average soil concentration.

The integral 10, 30, 50 and 70 year doses to the whole body, bone marrow and liver for each radionuclide via the terrestrial foodchain are listed in Table 23 for Eneu Island and Table 24 for Bikini Island. The altered diets are listed in Table 25 and 26. Table 25 represents the Bikini diet minus the Pandanus fruit and breadfruit and Table 26 reflects the doses for the case where the diet is from Eneu with the exception of coconut from Bikini. The Bikini data represent the average of areas 1, 2, 3 and 4 as previously described.

Focusing on the 30 year integral dose for the total diets from each island (Tables 23 and 24), it is clear that ^{137}Cs accounts for nearly all of the whole body exposure. ^{137}Cs accounts for approximately 60% of the bone marrow dose while ^{90}Sr accounts for the remaining 40%. ^{60}Co and $^{239,240}Pu$ are insignificant contributors via the terrestrial food chain relative to ^{137}Cs and ^{90}Sr. For comparative purposes the 30 year integral dose via the terrestrial foodchain on Bikini Island is 23 rem for whole body and 37 rem for bone marrow while on Eneu Island the respective doses are 2.0 rem and 3.3 rem. The 50 year integral doses of course show a similar difference. It is clear that the Eneu Island living pattern is much preferred to that of Bikini Island for reducing potential dose to returning populations.

The impact of removing from the diet Pandanus fruit and breadfruit grown on Bikini Island can be observed in Table 25. The bone marrow doses are reduced by nearly a factor of two (18 rem 30 year dose and 26 rem 50 year dose) while whole body doses are reduced by approximately 40% (14 rem 30 year dose and 20 rem 50 year dose). Removing all other items from Bikini Island from the diet with the exception of coconut, i.e., Eneu diet plus Bikini Island coconut, gives a further reduction in bone marrow and whole body dose of approximately 20% over removing Pandanus fruit and breadfruit only (see Table 26). However, comparing the Eneu only diet, Table 23, and the Eneu diet plus coconut from Bikini Island, Table 26, it is clear that inclusion of coconut from Bikini Island increases significantly the bone marrow and whole body doses relative to a diet totally derived from Eneu Island. For comparison, the 50 year bone marrow dose from a diet derived totally from Eneu is 4.7 rem while the Eneu diet plus coconut from Bikini leads to a dose of 21 rem. The 50 year whole body doses are 2.8 rem and 17 rem respectively.

E. Dose Summary and Discussion

Tables 27, 28, 29 and 30 lists the 10, 30, 50 and 70 year integral doses respectively for each exposure pathway, plus the sum of all exposure pathways, for each of the 6 living patterns. For reference the 30 year integral dose listed in Table 28 will be examined.

For Case 1 (living on Eneu Island and diet from Eneu Island) the terrestrial diet contributes 50% of the bone marrow dose and 40% of the whole body dose. The external gamma dose contributes nearly 44% of the bone marrow dose and 58% of the whole body dose. The marine pathway and drinking water pathway, assuming that the drinking water on Eneu is from the lens system, each contribute about 3% to the bone marrow dose and 1% or less to the whole body. Therefore, for Case 1, 94% of the bone marrow dose and 98% of the whole body dose are contributed by two pathways; terrestrial and external. For Case 6, living on Bikini Island and diet from Bikini Island, the terrestrial and external gamma pathways contribute 85.6% and 13.7% of the bone marrow dose and 79% and 20% of the whole body dose respectively. In other words, 99% of the total dose for Case 6 is the result of the terrestrial and external gamma pathways. The integral 30 year doses for bone marrow range from 6.6 rem for Case 1 (Eneu) to 43 rem for Case 6 (Bikini). The corresponding whole body doses are 5.0 rem for Case 1 to 29 rem for Case 6.

As dietary remedial measures are taken on Bikini Island, that is Cases 2, 3, 4 and 5 which are variations of Case 6, the relative contribution of the exposure pathways to total dose changes. However, the pathways which contribute the largest fraction of the total dose continue to be the terrestrial foodchain and external gamma. A summary of the percent contribution of each pathway to total dose for each living pattern is listed in Table 31.

The summation of the 30 year and 50 year integral doses for bone marrow and whole body for the six living patterns is listed in Table 32. The Eneu living pattern, Case 1, produces the lowest dose. All other living patterns lead to doses at least 3 times higher, and for the unmodified Bikini living pattern, Case 6, the doses are at least 6 times higher than for Eneu. It is clear, therefore, that Eneu Island provides, by a significant degree, the lowest dose living pattern at Bikini Atoll.

For comparison, the Federal guide for whole body and bone marrow dose for a member of the population is 0.5 rem per year. Over a 30 year period the guide totals 15 rem. The Eneu living pattern (Case 1) leads to predicted 30 year doses for whole body and bone marrow of 5.0 rem and 6.6 rem respectively which are below the Federal guides. Case 6 (the Bikini Island living pattern) results in predicted 30 year doses of 29 rem for the whole body and 43 rem for the bone marrow; these doses are approximately 2 to 2.5 times the Federal guides. The other living patterns (Case 2 thru Case 5), which include various remedial measures and are variations of the basic Case 6 living pattern, lead to predicted whole body doses which range from 17 to 20 rem and bone marrow doses which range from 19 rem to 25 rem. All of these are in excess of the Federal guide.

F. Comparison with Enewetak Atoll

Both Bikini and Enewetak Atoll's were sites for the United States nuclear testing program from 1948 through 1960. Recent requests by both the Bikini and Enewetak people to return to their home atolls have led to detailed radiological surveys to determine the status of the atolls and the impact, if any, of restrictions placed upon living patterns and life styles as a result of the dose assessment. The atolls are located within 300 miles of each other in the northern Marshalls. They have essentially the same topography, soil chemistry and biota. In addition to these physical similarities, the distribution of radionuclide contamination relative to the islands used for residence and the potential impact upon living patterns are somewhat similar.

At Enewetak Atoll the major residence islands for the Enewetak people prior to their relocation in 1947 were Engebi Island in the northern half of the atoll and Enewetak and Japtan Islands in the southern half of the atoll (see Figure 4). The people living on Engebi Island (dri Engebi) had their own chief (Iroj) and owned land right in the northern islands while the people living on Enewetak Island (dri Enewetak) had their own chief and owned land rights in the southern half of the atoll. Many tests were conducted in the northern half of the atoll and the major residence island, Engebi, was contaminated. The southern half of the atoll, on the other hand, is relatively "clean". The results of the Enewetak assessment indicate that a living pattern involving Engebi Island for both residence and agriculture involves potential doses in excess of regulatory guides while living patterns in the southern half of the atoll lead to doses similar to those in the United States (1).

The situation at Bikini Atoll is somewhat similar. The two major islands used for residence at Bikini Atoll were Bikini and Eneu (see Figure 1). The people living on Bikini Island own land rights on that island and those people living on Eneu own land rights there. Bikini Island was heavily contaminated as a result of the Bravo event; Eneu was contaminated to a lesser degree but, as will be seen is still more highly contaminated than the southern half of Enewetak Atoll.

The Survey of Enewetak Atoll was conducted in 1972 and the resulting assessment published in 1973 (31). Additional information on annual doses and on the impacts of remedial actions were published in the AEC Task Group Report (32). Decisions concerning the use of Enewetak Atoll were based upon these assessments.

The availability of this assessment for Bikini and Eneu Islands

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at Bikini Atoll allows comparison of the predicted doses at the two atolls. The predicted doses at each atoll are of course based upon assumptions concerning the time sequence of availability of key food products as outlined in the respective assessments. The predicted dose for the living pattern using Bikini Island for residence and for agricultural products exceeds any predicted for Enewetak, primarily because key food products will be available on a much shorter time scale.

The doses predicted for the primary living patterns at the two atolls are listed in Table 33. The highest predicted doses occur for the living pattern involving Bikini Island, Case 6, at Bikini Atoll. The integral 30 year whole body and bone marrow doses and 29 and 43 rem respectively. The predicted doses are approximately 2.5 times higher than those predicted for Engebi Island at Enewetak Atoll (whole body 11 rem, bone marrow 16 rem) which is the living pattern leading to the second highest predicted doses at the atolls. Eneu Island, Case 1, at Bikini Atoll ranks third in the list of four major living patterns at the two atolls. The whole body dose of 5.0 rem and bone marrow dose of 6.6 rem for Eneu are approximately a factor of two lower than those predicted for Engebi Island at Enewetak Atoll. However the Eneu doses are about five times higher than the southern island living patterns at Enewetak. The southern island living patterns at Enewetak lead to the lowest predicted doses of all living patterns at either atoll (1.0 rem whole body, 1.2 rem bone marrow), and are in fact lower than U.S. doses.

Bone doses presented in the Enewetak Radiological Survey (1) were calculated for mineral bone. These mineral bone doses are compared to the federal guide of 3 rem/year for a member of the population. The doses in this report, and in the AEC Task Group Report (32) for Enewetak Atoll, were calculated for bone marrow and are compared to the federal guide of 0.5 rem/year for a member of the population. The bone doses listed for Enewetak Atoll in the Enewetak Radiological Survey Report (1) have been converted to bone marrow doses and included in Table 33 to allow comparison with doses from Bikini Atoll.

The federal guides for whole body and bone marrow are listed in the last column of Table 33 for comparison with the predicted doses for each of the major living patterns at the two atolls. Doses predicted for Bikini Island exceed the guidelines while the Engebi Island living pattern is very marginal. Eneu Island and the southern half of Enewetak Atoll lead to predicted doses below the federal guides.

The accepted methodology for evaluating living patterns on Enewetak Atoll was to reduce the federal guides by 50% to compensate for the fact that "the doses cannot be precisely predicted" (32). If a similar method is adopted for Bikini Atoll then the reference guide would be 0.25 rem/year for whole body and bone marrow, or 7.5 rem over 30 years. In this case Bikini Island and Engebi Island definitely exceed the guides and Eneu Island is marginal. The southern half of Enewetak Atoll is of course no problem. In fact, the predicted doses for the southern half of Enewetak Atoll are less than those expected from natural background radiation exposure in the United States (see Table 33).

In final analysis it would appear that for living patterns using diets composed of locally grown products and using the larger islands which are more suitable for residence (i.e., Bikini and Eneu Islands) no living pattern is possible at Bikini Atoll which would lead to as low a dose as is possible at Enewetak in the southern half of that atoll. Preliminary data (22) from the only other large island at Bikini Atoll, i.e., Namu, indicate that predicted doses for this island would be more similar to those predicted for Bikini Island.

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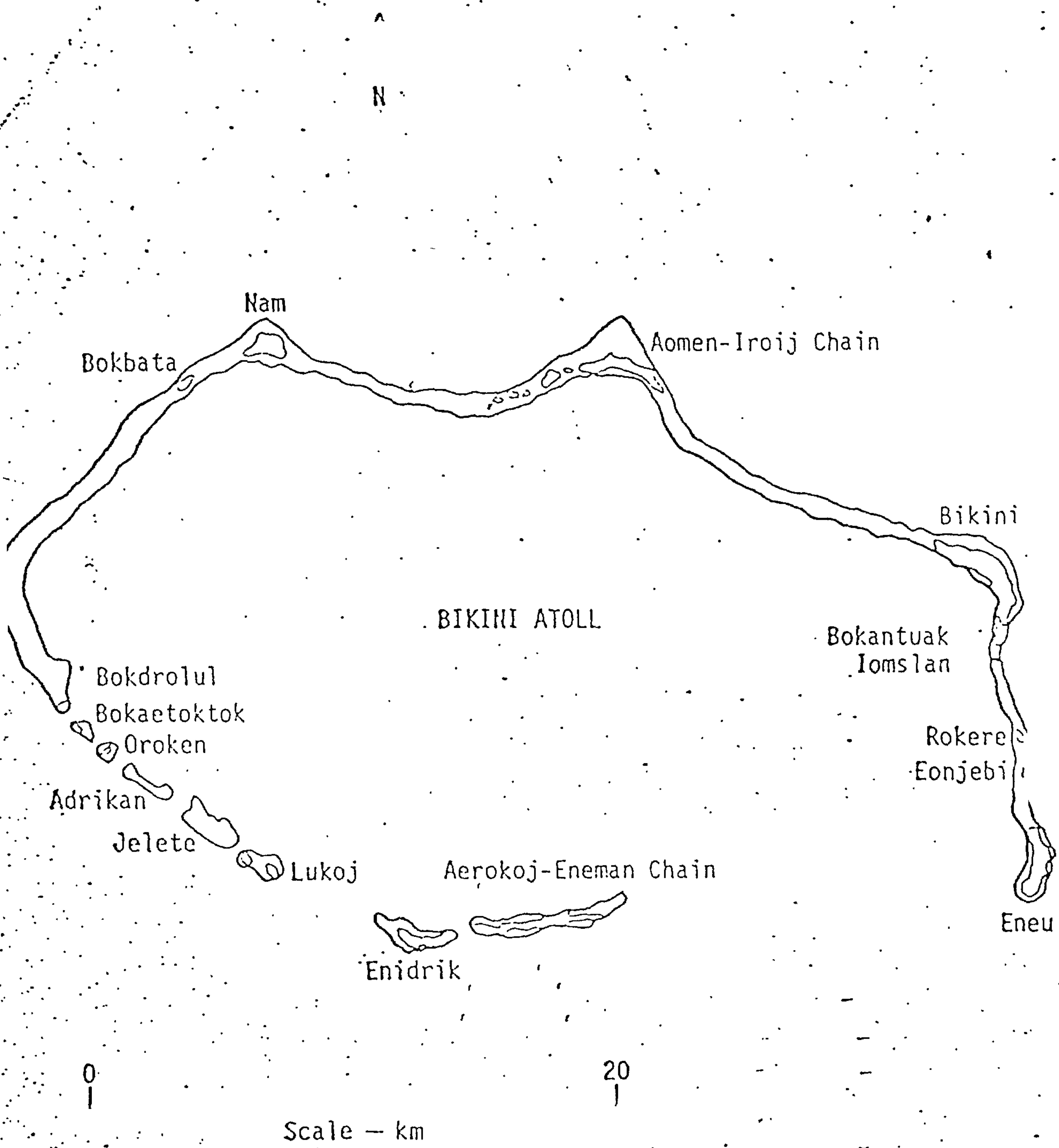

Fig. 1. Map of Bikini Atoll

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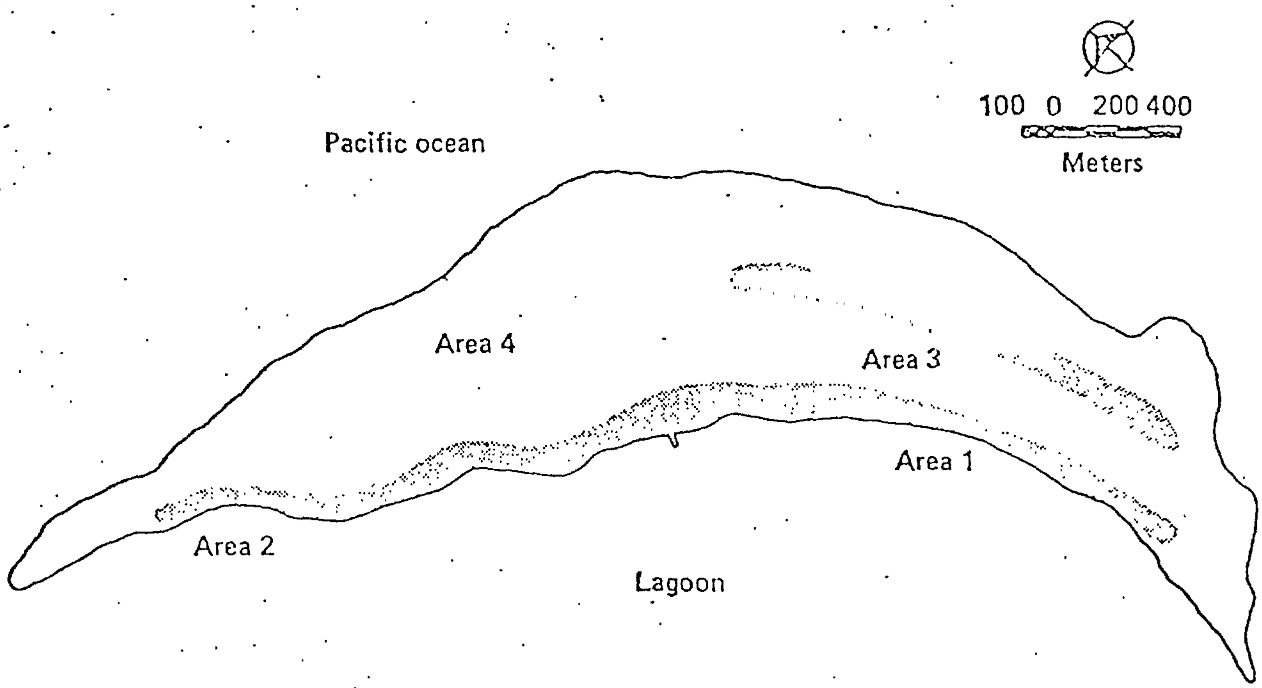

Fig. 2 A map of Bikini Island showing specific areas of interest for the dose calculations. Existing houses are situated within area 1. Areas 2 and 3 are proposed village sites for future housing units. The interior portion of the island is denoted by area 4.

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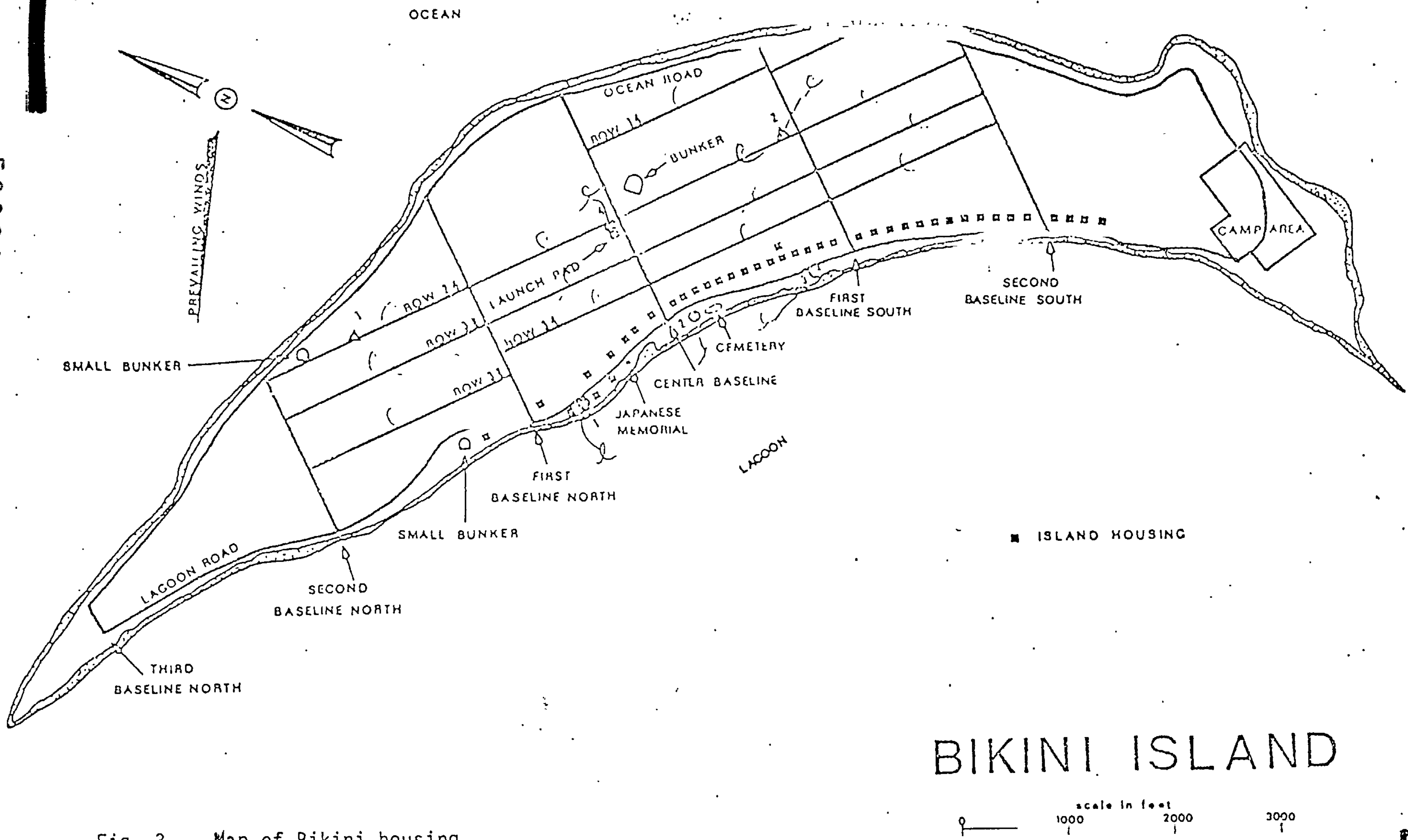

Fig. 3. Map of Bikini housing layout

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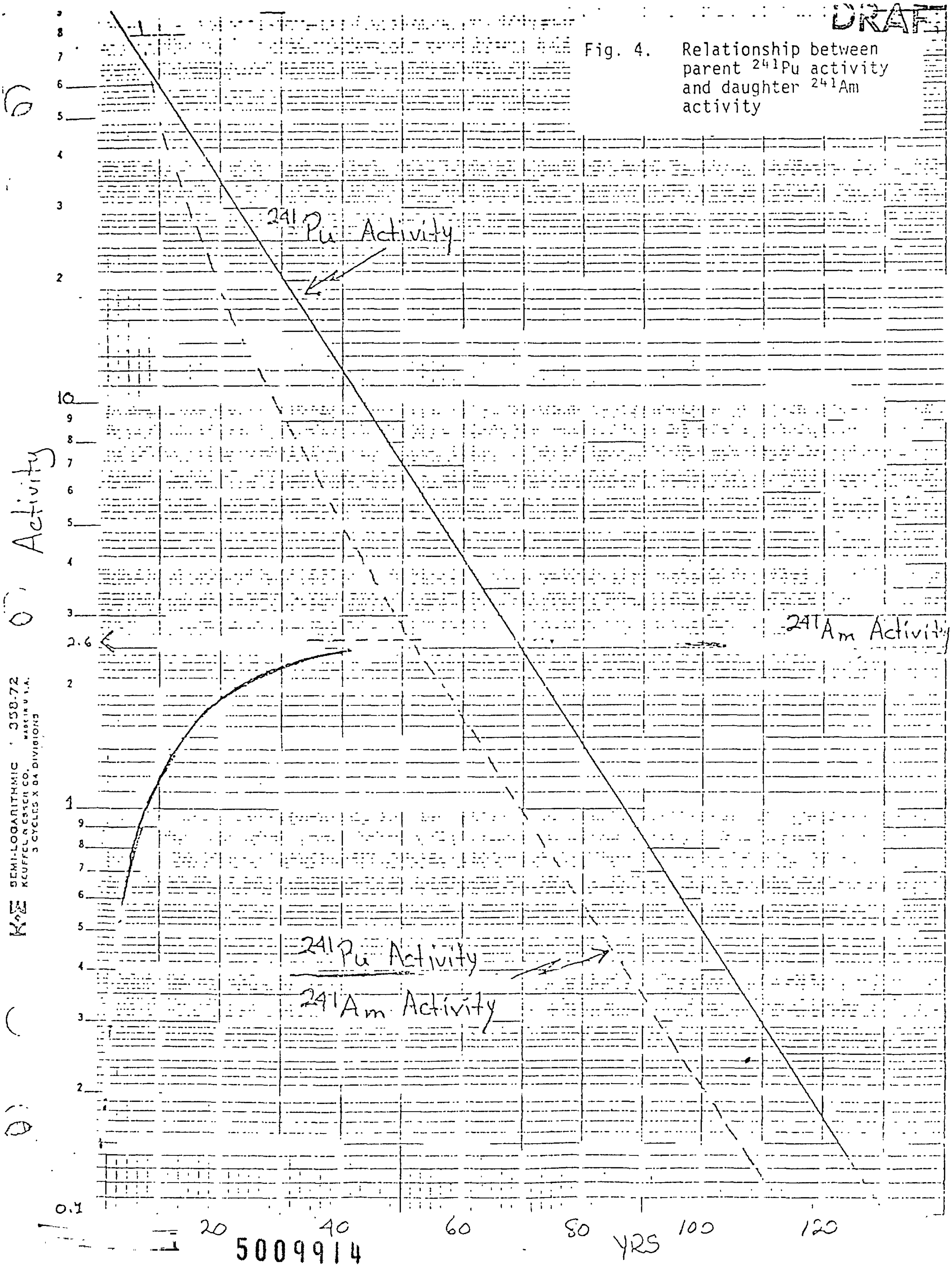

Fig. 4. Relationship between parent ^{241}Pu activity and daughter ^{241}Am activity

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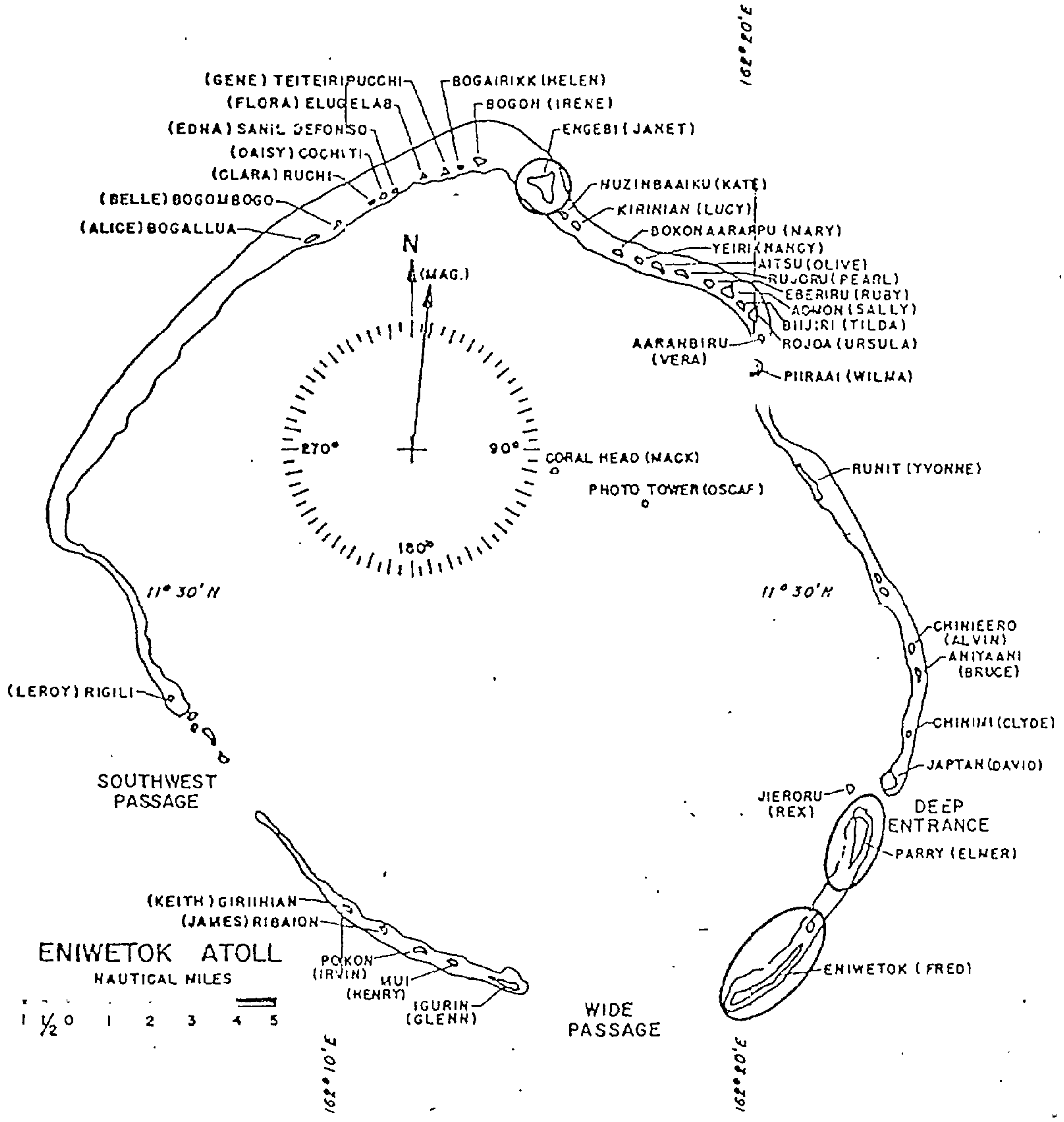

Fig. 5. Map of Enewetak Atoll

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Table 1. Assumed living patterns.

Case	Description
1	No use of Bikini Island for the present as a housing or food production area. Use of Eneu Island for housing and food production. Unrestricted use of fish throughout the atoll.
2	Limited use of Bikini Island with residence in houses already constructed. No additional house construction on Bikini Island for the present. Use of coconuts grown on Bikini Island. Other food crops grown on Eneu Island only. Unrestricted use of fish from all parts of the atoll. Use of Bikini Island lens water for agriculture only.
3	Limited use of Bikini Island with the following remedial actions taken: (a) placing 5 cm of clean coral gravel around the existing houses out to a distance of 10 m, and (b) removal of the top 20 cm of soil and replacement with clean soil out to a distance of 10 m around the houses. All foods grown on Bikini Island are acceptable except pandanus and breadfruit. Unrestricted use of fish throughout the atoll. Use of Bikini Island lens water for agriculture only.
4	Limited use of Bikini Island with Phase II houses constructed only along the lagoon road within area 2 of Fig. 7. Remedial actions 3a and 3b are taken. Use of coconuts grown on Bikini Island. No use of pandanus and breadfruit from Bikini Island. Unrestricted use of fish throughout the atoll.
5	Phase II housing construction according to the Preliminary Bikini Atoll Master Plan, but no use of pandanus and breadfruit from Bikini Island. Unrestricted use of fish throughout the atoll. Lens water for agriculture and washing only.
6	Phase II housing constructed according to the Preliminary Bikini Atoll Master Plan. All foods grown on Bikini Island are acceptable. Unrestricted use of fish throughout the atoll. Lens water used for agriculture and washing only.

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Table 2. Estimated Diet for Bikini and Eneu Islands

	Intake in Grams per Day		
	1975		1980
Food Item	Bikini	Eneu	Bikini and Eneu
Fish	600	600	600
Domestic meat	100	100	100
Pandanus Fruit	50	-	200
Breadfruit	50	-	150
Wild Birds	20	20	20
Bird Eggs	10	10	10
Coconut Meat	100	100	100
Coconut Milk	100	100	300
Coconut Crab	25	25	25
Clams	25	25	25
Garden Vegetables	50	50	50
Total	1130	1030	1580

plus imports

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Table 3. Disintegration Energy (E) and Fractional Deposition (F) in Reference Organ for Five Major Radionuclides.

Radionuclide	E(MeV)	Bone F	Liver F	Whole Body F
^{137}Cs	0.59	-	-	1.0
^{90}Sr	1.1	0.3	-	-
^{60}Co	0.87	-	-	0.3
$^{239,240}Pu$	53	1.35(-5)	1.20(-5)	-

Table 4. Estimated integral whole-body external gamma doses for the first year and for 30 years. Values include contributions due to natural background radiation of about 0.027 rem for a first-year dose and 0.80 rem for a 30-year dose. For comparison, the federal radiation guide (total of external and internal doses) is 0.5 rem per year for individuals and 5 rem for 30 years for a population average. These guides are in excess of natural background.

Case	Description	Estimated doses (rem) First year	30 year
1	Village on Eneu Island	0.12	2.9
2	Residence in houses already constructed along lagoon road on Bikini Island.	0.20	4.3
3	Residence in houses already constructed along lagoon road on Bikini Island with following remedial actions taken:		
	a. Placing 5 cm of gravel around houses	0.18[a]	4.1[a]
	b. Removing and replacing top 20 cm of soil around houses	0.18[a]	4.0[a]
4	Residence in Phase II houses constructed along lagoon road within area 2 of Fig. 7 with following remedial actions taken:		
	a. Placing 5 cm of gravel around houses	0.22[a]	4.8[a]
	b. Removing and replacing top 20 cm of soil around houses	0.20[a]	4.4[a]
5	Residence in Phase II houses constructed within the interior of Bikini Island	0.28	5.9
6	Residence in Phase II houses constructed within the interior of Bikini Island	0.28	5.9

[a]The exposure rates in the immediate vicinity of the houses have been reduced by a factor of two and eight for remedial actions a and b, respectively. However, we have estimated that only 35 to 40% of the Bikinian's time will be spent in the vicinity of his house; therefore, the reduction in total dose is relatively small because the total dose includes the exposure received from the areas where he spends the other 60 to 65% of his time.

Table 5

$^{239,240}Pu$ Integral Dose - Rem Inhalation Pathway

Island	Lung				Liver				Bone			
	10 yr	30 yr	50 yr	70 yr	10 yr	30 yr	50 yr	70 yr	10 yr	30 yr	50 yr	70 yr
Bikini	4.6(-2)	0.16	0.28	0.39	3.1(-3)	3.9(-2)	0.11	0.20	3.9(-3)	5.3(-2)	0.16	0.31
Eneu	6.8(-3)	2.4(-2)	4.1(-2)	5.8(-2)	4.5(-4)	5.8(-3)	1.6(-2)	3.0(-2)	5.7(-4)	7.8(-3)	2.3(-2)	4.6(-2)

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Table 6. Analytical data from cistern water sampled on 21 June 1975 on Bikini Island (Bikini Atoll).

		Radionuclides (pCi/l)[a]	
Bldg.	^{137}Cs	^{90}Sr	$^{239,240}Pu$
5	2.5(1)	1.1(11)	7.9×10^{-3}(5)
24	1.8(2)	1.9(2)	13.7×10^{-3}(4)
School	1.7(2)	1.42(7)	29.0×10^{-3}(2)
Mean	2.0	1.47	1.69×10^{-2}

[a]The values in parentheses are the 1-σ counting errors expressed as percentages of the listed values.

Table 7. Radionuclide Concentration in the Ground Water of Bikini and Eneu Islands

Bikini

		Concentration[a]						
		^{137}Cs (pCi/l)		^{90}Sr (pCi/l)		$^{239,240}Pu$ (fCi/l)		Ratio $^{238/239,240}Pu$
		Sol.	Part.	Sol.	Part.	Sol.	Part.	Sol.
HFH 1	(0840 hr)	480	9.9	87(1)	1.31	40.0	3.3(13)	0.026(9)
	(1145 hr)	629	10.9	46(1)	0.57	5.9	1.3(32)	<0.004
	(1545 hr)	695	15.6	38(1)	0.48	4.7	1.9(21)	<0.004
HFH 2		294	12.0	77	1.37	7.5	71.3(4)	0.04 (35)
HFH 3		335	8.3	227		38.2	8.4(10)	<0.008
HFH 4		226	6.5	260		89	33.2	<0.001
HFH 5		530	8.5	180		25.6	13.4(12)	0.004(60)
HFH 7		250	5.8	1.0		9.8	2.0(22)	0.022(30)

Eneu

		Concentration[a]					
		^{137}Cs (pCi/l)		^{90}Sr (pCi/l)		^{239}Pu (fCi/l)	
Well	Hour sampled	Sol.	Part.	Sol.	Part.	Sol.	Part.
FWR 1	0835	35.3(1)	1.17(2)	71 (1)	0.81	3.5(6)	9.5 (10)
	1250	30 (1)	0.73(3)	45.6(1)	0.56	3.3(8)	1.6 (22)
FWR 2		69.1(1)	0.95(3)	66 (2)		23.5(4)	8.4 (17)
FWR 3S[b]		32 (2)	0.59(2)	1.3(13)	0.03	0.72(22)	1.42(16)
3B[b]		20 (3)	0.49(5)	1.0(9)		0.32(30)	1.1 (15)
FWR 4		1.1(5)	0.57(2)	3.4(5)	0.11	0.85(18)	0.67(27)

[a]Sol.: soluble fraction; Part.=particulate fraction. The values in parentheses are the 1-σ counting errors expressed as percentages of the listed values. [b]S. surface; B. bottom

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Table 8. Integral Dose - Rem

Bikini Cistern Water

Radionuclide	10 year			30 year			50 year			70 year		
	W.B.	Bone marrow	Liver	W.B.	Bone marrow	Liver	W.B.	Bone marrow	Liver	W.B.	Bone marrow	Liver
^{137}Cs	7.5 (-4)	7.5 (-4)	7.5 (-4)	1.9 (-3)	1.9 (-3)	1.9 (-3)	2.6 (-3)	2.6 (-3)	2.6 (-3)	3.0 (-3)	3.0 (-3)	3.0 (-3)
^{90}Sr	-	3.1 (-3)	-	-	9.1 (-3)	-	-	1.3 (-2)	-	-	1.5 (-2)	-
$^{239,240}Pu$	-	6.9 (-6)	5.4 (-6)	-	5.9 (-5)	4.4 (-5)	-	1.6 (-4)	1.1 (-4)	-	3.0 (-4)	1.9 (-4)
Total	7.5 (-4)	3.8 (-3)	7.5 (-4)	1.9 (-3)	1.1 (-2)	1.9 (-3)	2.6 (-3)	1.6 (-2)	2.7 (-3)	3.0 (-3)	1.9 (-2)	3.2 (-3)

Table 9. Integral Dose - Rem

Bikini Ground Water

Radionuclide	10 year W.B.*	10 year Bone marrow	10 year Liver	30 year W.B.	30 year Bone marrow	30 year Liver	50 year W.B.	50 year Bone marrow	50 year Liver	70 year W.B.	70 year Bone marrow	70 year Liver
^{137}Cs	0.16	0.16	0.16	0.41	0.41	0.41	0.56	0.56	0.56	0.66	0.66	0.66
^{90}Sr	-	0.24	-	-	0.73	-	-	1.0	-	-	1.2	-
$^{239,240}Pu$	-	1.1 (-5)	8.8 (-6)	-	9.7 (-5)	7.1 (-5)	-	2.6 (-4)	1.8 (-4)	-	4.8 (-4)	3.2 (-4)
Total	0.16	0.41	0.16	0.41	1.1	0.41	0.56	1.6	0.56	0.66	1.9	0.66

*W.B. = Whole Body

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Table 10. Integral Dose - Rem

Eneu Ground Water

Radionuclide	10 year W.B.	10 year Bone marrow	10 year Liver	30 year W.B.	30 year Bone marrow	30 year Liver	50 year W.B.	50 year Bone marrow	50 year Liver	70 year W.B.	70 year Bone marrow	70 year Liver
^{137}Cs	1.2 (-2)	1.17(-2)	1.2 (-2)	2.9 (-2)	2.9 (-2)	2.9 (-2)	4.0 (-2)	4.0 (-2)	4.0 (-2)	4.7 (-2)	4.7 (-2)	4.7 (-2)
^{90}Sr	-	6.6 (-2)	-	-	0.20	-	-	0.28	-	-	0.33	-
$^{239,240}Pu$	-	2.2 (-6)	1.7 (-6)	-	1.9 (-5)	1.4 (-5)	-	5.0 (-5)	3.5 (-5)	-	9.4 (-5)	6.2 (-5)
Total	1.2 (-2)	7.7 (-2)	1.2 (-2)	2.9 (-2)	0.22	2.9 (-2)	4.0 (-2)	0.32	4.0 (-2)	4.7 (-2)	0.37	4.7 (-2)

*W.B. = Whole Body

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Table 11. Radionuclide Concentrations in Clams at Bikini Atoll.

Date Collectec	Island	Species	Tissue	No. in Sample	pCi/g dry weight ^{60}Co	^{137}Cs	^{90}Sr	$^{239,240}Pu$	Source
April, 1975	Eneu	Goatfish	E.W.*	1	1.6	0.18	0.23	0.003	Vic Nelson unpublishe
"	"	"	E.W.	1	1.0	0.18	<0.07	0.003	
"	"	Convict Surgeor	E.W.	1	0.27	0.25	0.07	-	"
"	"	"	E.W.	1	0.19	0.18	<0.07	0.005	"
"	"	Grouper	Muscle	1	0.16	0.43	<0.03	-	"
"	"	Parrot fish	Muscle	1	-	0.43	<0.03	-	"
"	Namu	Convict Surgeor	E.W.	1	1.7	4.5	<0.26	-	"
"	Enidrik	"	E.W.	1	0.68	0.48	0.17	0.020	"
Dec 74/Apr 75	Namu	Mullet	E.W.	1	2.0	0.32	0.12	<0.01	"
"	Enidrik	"	E.W.	1	0.82	0.14	0.05	<0.002	"
"	"	"	E.W.	1	1.4	0.32	<0.06	0.008	"
April, 1974	Bikini	Goatfish	Entire	1	-	-	0.06	0.004	"
"	"	Mullet	E.W.	3	3.50	0.12	0.24	0.020	"
"	"	"	E.W.	3	1.90	0.72	0.18	0.045	"
Nov 71;March and May 72	Namu	"	E.W.	14	4.3	0.25	-	-	Lynch et a (22)
	"	"	E.W.	12	4.1	0.59	0.16	-	
"	"	"	E.W.	2	18	1.2	-	-	"
"	Bikini	Convict Surgeon	E.W.	10	1.0	0.7	-	-	"
"	"	"	E.W.	14	0.9	0.51	0.15	-	"
"	Eneman	"	E.W.	16	1.0	0.20	0.07	-	"
"	"	Goatfish	E.W.	1	0.67	0.08	<0.03	-	"
"	Nam	"	E.W.	12	26	0.51	1.0	-	"
"	"	Snapper	Muscle	6	3.2	0.99	-	-	"
October 72	Bikini	Surgeon Fish	Muscle	3	-	-	-	0.0016	Nevissi & Schell (22)
"	Bokbata	"	E.W.	1	-	-	-	0.028	
"	Several	Convict Surgeon	Muscle	39	-	-	-	<0.0016	"
"	Bokbata	"	E.W.	4	-	-	-	0.044	"
"	Nam	"	E.W.	1	-	-	-	0.016	"
"	"	"	E.W.	4	-	-	-	0.027	"

* E.W. ≡ Eviscerated Whole

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Table 12. Radionuclide Concentrations in Clams at Bikini Atoll.

Date Collected	Species	Tissue	pCi/g dry weight ^{60}Co	^{137}Cs	^{90}Sr	$^{239,240}Pu$	Source
Nov. 1972	Tridacna gigas	Muscle	0.2	<0.05	-	-	Bill Schell (unpublished)
"	Tridacna crocea	Muscle + Mantle	5.5	<0.05	-	-	"
"	Hippopus sp.	" "	4.9	<0.05	-	-	"
"	Tridacna crocea	" "	32	<0.05	-	-	"
April 1975	Tridacna gigas	Mantle	9.5	<0.05	<0.03	0.04	Vic Nelson (unpublished)
"	" "	Muscle	4.9	0.17	<0.03	0.012	"

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Table 13. Average Weighted Radionuclide Concentrations in Fish and Clams at Bikini Atoll.

	pCi/g Wet Weight			
Species	^{60}Co	^{137}Cs	^{90}Sr	$^{239,240}Pu$
Fish	1.51	0.14	0.076	0.0028
Clams	2.06	0.011	0.0060	0.0072

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Table 14. Radionuclide Concentrations in Birds and Bird Eggs at Bikini Atoll.

Source	Island	Species	Sample	Tissue	pCi/g wet weight ^{60}Co	^{137}Cs	^{90}Sr	$^{239,240}Pu$
Lynch et al (22)	Oroken	Fairy Tern	1	Muscle	0.26	0.079	-	-
Held (30)	"	Noddy Tern	5	Muscle	1.3	0.15	-	-
"	"	" "	5	Liver	2.7	<0.4	-	-
"	"	Fairy Tern	5	Muscle	0.29	<0.4	-	-
"	"	" "	5	Liver	0.42	<0.4	-	-
Vic Nelson (unpublished)	Nam	Sooty and Noddy Tern	4	Muscle	0.30	<0.017	0.013	-
"	"	Bird Eggs	-	Shelled Egg	0.06	0.13	0.07	-

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Table 15. Average Radionuclide Concentrations in Birds and Bird Eggs at Bikini Atoll.

pCi/g wet weight

	^{60}Co	^{137}Cs	^{90}Sr	$^{239,240}Pu$
Birds	0.76	0.22	0.04	0.022
Bird Eggs	0.015	0.033	0.018	0.0059

Table 16. Integral Dose - Rem

Marine Food Chain

Radionuclide	10 year			30 year			50 year			70 year		
	W.B.*	Bone marrow	Liver	W.B.	Bone marrow	Liver	W.B.	Bone marrow	Liver	W.B.	Bone marrow	Liver
^{137}Cs	1.7(-2)	1.7(-2)	1.7(-2)	4.2(-2)	4.2(-2)	4.2(-2)	5.8(-2)	5.8(-2)	5.8(-2)	6.8(-2)	6.8(-2)	6.8(-2)
^{60}Co	6.1(-3)	6.1(-3)	6.1(-3)	8.1(-3)	8.1(-3)	8.1(-3)	8.3(-3)	8.3(-3)	8.3(-3)	8.3(-3)	8.3(-3)	8.3(-3)
^{90}Sr	-	5.0(-2)	-	-	1.5(-1)	-	-	2.1(-1)	-	-	2.5(-1)	-
$^{239,240}Pu$	-	4.9(-4)	3.8(-4)	-	4.2(-3)	3.1(-3)	-	1.1(-2)	7.8(-3)	-	2.1(-2)	1.4(-2)
Total	2.3(-2)	7.4(-2)	2.3(-2)	5.0(-2)	2.0(-1)	5.3(-2)	6.6(-2)	2.9(-1)	7.4(-2)	7.6(-2)	3.5(-1)	9.0(-2)

*W. B. Means Whole Body

Table 17. Soil-mature leaf concentration factors calculated from associated[a] and unassociated[b] data.

	Concentration Factor, (pCi/g dry plant)/(pCi/g dry soil)							
	Associated				Unassociated			
Nuclide, Species	No. of Samples	Minimum	Maximum	Median	No. of Samples	Minimum	Maximum	Median
^{90}Sr, *Scaevola*	2	0.24	0.41	0.33	4	0.048	4.3	1.8
^{90}Sr, coconut	7	0.099	0.38	0.16	15	0.041	0.74	0.29
^{137}Cs, *Scaevola*	2	1.3	14	7.5	4	0.073	39	7.7
^{137}Cs, coconut	8	1.1	16	3.0	15	0.53	18	2.6
^{239}Pu, coconut	4	0.011	0.022	0.015	12	0.0036	0.14	0.016
^{240}Pu, coconut	4	0.011	0.021	0.015	12	0.0021	0.15	0.016

[a] Plant and soil data sampled from the same site

[b] Plant and soil data sampled from different sites in the same general area.

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Table 17. Soil-mature leaf concentration factors calculated from associated[a] and unassociated[b] data.

	Concentration Factor, (pCi/g dry plant)/(pCi/g dry soil)							
	Associated				Unassociated			
Nuclide, Species	No. of Samples	Minimum	Maximum	Median	No. of Samples	Minimum	Maximum	Median
^{90}Sr, *Scaevola*	2	0.24	0.41	0.33	4	0.048	4.3	1.8
^{90}Sr, coconut	7	0.099	0.38	0.16	15	0.041	0.74	0.29
^{137}Cs, *Scaevola*	2	1.3	14	7.5	4	0.073	39	7.7
^{137}Cs, coconut	8	1.1	16	3.0	15	0.33	18	2.6
^{239}Pu, coconut	4	0.011	0.022	0.015	12	0.0036	0.14	0.016
^{240}Pu, coconut	4	0.011	0.021	0.015	12	0.0021	0.15	0.016

[a] Plant and soil data sampled from the same site

[b] Plant and soil data sampled from different sites in the same general area.

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Table 18. Measured and Estimated Radionuclide Concentrations in Food Products on Bikini and Eneu Islands at Bikini Atoll.

Bikini Terrestrial Foods

pCi/g wet weight

January 1, 1975

Food Product	^{90}Sr	^{137}Cs	^{60}Co	$^{239,240}Pu$
Pandanus Fruit	7.60	46.7	<1.30(-2)	<4.81(-3)
Breadfruit	17.3	90.5	<3.59(-2)	<6.12(-3)
Coconut Meat(dry wt.)	1.82	108	<0.111	<1.06(-2)
Coconut Milk	0.851	50.6	<0.103	<9.01(-3)
Domestic Meat	0.201	22.2	<1.05(-2)	<1.42(-2)
Coconut Crabs	220	47.6	1.09	6.8(-3)
Garden Vegetables	12.9	56.7	7.40(-3)	<5.56(-4)

Eneu Terrestrial Foods

pCi/g wet weight

January 1, 1975

Food Product	^{90}Sr	^{137}Cs	^{60}Co	$^{239,240}Pu$
Pandanus Fruit	0.407	3.09	<1.02(-3)	<3.96(-4)
Breadfruit	0.924	5.99	<2.82(-3)	<5.03(-4)
Coconut Meat(dry wt.)	9.76(-2)	7.16	<8.74(-3)	<1.86(-2)
Coconut Milk	4.56(-2)	3.35	<8.07(-3)	<7.41(-3)
Domestic Meat	<1.08(-2)	1.47	<8.24(-4)	<1.17(-3)
Coconut Crabs	220	47.6	1.09	6.8(-3)
Garden Vegetables	0.689	3.75	5.82(-4)	<4.57(-5)

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Table 19. Total Diet from Eneu

Nuclide	pCi/day Intake 1975*	1980
^{60}Co	29.1	35
^{137}Cs	2575	4243
^{90}Sr	270	412
$^{239,240}Pu$	0.438	0.740

* Minus pandanus fruit and breadfruit

Table 20. Total Diet from Bikini Island

pCi/day Intake

	Area 1		Area 2		Area 3		Area 4		Mean of Areas 1,2,3 and 4	
Nuclide	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
^{60}Co	45	33	56	44	55	43	54	42	52.5	40.5
^{137}Cs	23,577	39,427	28,893	48,986	31,498	53,685	31,997	54,595	28,991	49,173
^{90}Sr	1415	2726	3810	7841	2186	3882	2163	3836	2394	4571
$^{239,240}Pu$	3.44	5.89	5.15	9.86	3.27	5.48	4.0	7.18	3.97	7.10

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Table 21. Bikini Diet minus Pandanus and Breadfruit

	pCi/day Intake									
	Area 1		Area 2		Area 3		Area 4		Mean of Areas 1,2,3 and 4	
Nuclide	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
^{60}Co	43.3	32.4	53.2	42.6	52.3	41.8	51.4	40.9	50.1	39.4
^{137}Cs	18,175	24,668	22,060	29,994	23,965	32,612	24,330	33,119	22,133	30,098
^{90}Sr	737	931	1750	1997	1064	784	1054	779	1151	1123
$^{239,240}Pu$	3.02	4.58	4.34	7.19	2.88	4.30	3.45	5.42	3.42	5.37

Table 22. Eneu Diet with Coconut from Bikini

	pCi/day Intake									
	Area 1		Area 2		Area 3		Area 4		Mean of Area 1,2,3 and 4	
Nuclide	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
^{60}Co	41.8	33	51.4	42.8	50.5	41.9	49.9	41.3	48.4	39.8
^{137}Cs	14,049	20,991	17,347	25,794	18,963	28,155	19,272	28,612	17,408	25,888
^{90}Sr	401	604	698	1035	497	743	494	738	523	780
$^{239,240}Pu$	1.74	3.25	3.04	5.85	1.60	2.41	2.16	4.10	2.14	3.90

Table 23. Integral Dose - Rem

Eneu Terrestrial Food Chain

Radionuclide	10 year W.B.*	10 year Bone marrow	10 year Liver	30 year W.B.	30 year Bone marrow	30 year Liver	50 year W.B.	50 year Bone marrow	50 year Liver	70 year W.B.	70 year Bone marrow	70 year Liver
^{137}Cs	6.7(-1)	6.7(-1)	6.7(-1)	2.0	2.0	2.0	2.8	2.8	2.8	3.3	3.3	3.3
^{90}Sr	-	3.6(-1)	-	-	1.3	-	-	1.9	-	-	2.3	-
^{60}Co	3.3(-4)	3.3(-4)	3.3(-4)	5.4(-4)	5.4(-4)	5.4(-4)	5.6(-4)	5.6(-4)	5.6(-4)	5.6(-4)	5.6(-4)	5.6(-4)
$^{239,240}Pu$	-	1.0 (-4)	8.05(-5)	-	1.1 (-3)	8.3 (-4)	-	3.2 (-3)	2.21(-3)	-	6.1 (-3)	4.0 (-3)
Total	0.67	1.03	.67	2.0	3.3	2.0	2.8	4.7	2.8	3.3	6.6	3.3

*W. B. Means Whole Body

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Table 24. Terrestrial Foodchain Integral Dose-Rem

Bikini Average of Areas 1,2,3 and 4 Total

Radionuclide	10 Year W.B.*	10 Year Bone Marrow	10 Year Liver	30 Year W.B.	30 Year Bone Marrow	30 Year Liver	50 Year W.B.	50 Year Bone Marrow	50 Year Liver	70 Year W.B.	70 Year Bone Marrow	70 Year Liver
^{137}Cs	7.6 [1.1]	7.6 [1.1]	7.6 [1.1]	23 [3.2]	23 [3.2]	23 [3.2]	33 [4.5]	33 [4.5]	33 [4.5]	39 [5.4]	39 [5.4]	39 [5.4]
^{90}Sr	—	3.6 [1.7]	—	—	14 [6.7]	—	—	21 [10]	—	—	25 [12]	—
^{60}Co	5.0(-4) [4.8(-5)]	5.0(-4) [4.8(-5)]	5.0(-4) [4.8(-5)]	7.8(-4) [8.1(-5)]	7.8(-4) [8.1(-5)]	7.8(-4) [8.1(-5)]	8.0(-4) [8.1(-5)	8.0(-4) [8.1(-5)]	8.0(-4) [8.1(-5)]	8.0(-4) [8.1(-5)]	8.0(-4) [8.1(-5)]	8.0(-4) [8.1(-5)]
$^{239,240}Pu$	—	9.0(-4) [2.0(-4)]	7.1(-4) [1.5(-4)]	—	1.1(-2) [2.7(-3)]	7.7(-3) [2.0(-3)]	—	3.0(-2) [8.0(-3)]	2.1(-2) [5.5(-3)]	—	5.8(-2) [1.6(-2)]	3.8(-2) [1.0(-2)]
TOTAL	7.6	11	7.6	23	37	23	33	53	33	39	63	39

*W.B. = Whole Body

[σ in brackets]

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Table 25. Terrestrial Foodchain Integral Dose - Rem

Bikini Average of Areas 1,2,3 and 4 minus Pandanus and Breadfruit

Radionuclide	W.B.*	10 Year Bone Marrow	Liver	W.B.	30 Year Bone Marrow	Liver	W.B.	50 Year Bone Marrow	Liver	W.B.	70 Year Bone Marrow	Liver
^{137}Cs	5.1 [0.66]	5.1 [0.66]	5.1 [0.66]	14 [1.9]	14 [1.9]	14 [1.9]	20 [2.6]	20 [2.6]	20 [2.6]	24 [3.1]	24 [3.1]	24 [3.1]
^{90}Sr	—	1.3 [0.53]	—	—	3.9 [1.9]	—	—	5.5 [2.7]	—	—	6.5 [3.2]	—
^{60}Co	4.8(-4) [4.7(-5)]	4.8(-4) [4.7(-5)]	4.8(-4) [4.7(-5)	7.4(-4) [8.0(-5)]	7.4(-4) [8.0(-5)]	7.4(-4) [8.0(-5)]	7.6(-4) [8.0(-5)]	7.6(-4) [8.0(-5)]	7.6(-4) [8.0(-5)]	7.6(-4) [8.0(-5)]	7.6(-4) [8.0(-5)]	7.6(-4) [8.0(-5)]
$^{239,240}Pu$	—	7.6(-4) [1.5(-4)]	5.9(-4) [1.2(-4)]	—	8.2(-3) [1.9(-3)]	6.0(-3) [1.4(-3)]	—	2.3(-2) [5.3(-3)]	1.6(-2) [3.7(-3)]	—	4.5(-2) [1.0(-2)]	2.9(-2) [6.9(-3)]
TOTAL	5.1	6.4	5.1	14	18	14	20	26	20	24	31	24

*W.B. = Whole Body

[σ in brackets]

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able 26. Terrestrial Foodchain Integral Dose - Rem

Bikini Average of Areas 1,2,3 and 4 Eneu Diet Plus Only Coconut from Bikini Island

	10 Year			30 Year			50 Year			70 Year		
Radionuclide	W.B.*	Bone Marrow	Liver	W.B.	Bone Marrow	Liver	W.B.	Bone Marrow	Liver	W.B.	Bone Marrow	Liver
^{137}Cs	4.2 [0.58]	4.2 [0.58]	4.2 [0.58]	12 [1.6]	12 [1.6]	12 [1.6]	17 [2.3]	17 [2.3]	17 [2.3]	21 [2.8]	21 [2.8]	21 [2.8]
^{90}Sr	—	0.69 [0.16]	—	—	2.5 [0.58]	—	—	3.6 [0.84]	—	—	4.3 [1.0]	—
^{60}Co	4.7(-4) [3.9(-5)]	4.7(-4) [3.9(-5)]	4.7(-4) [3.9(-5)]	7.3(-4) [6.7(-5)]	7.3(-4) [6.7(-5)]	7.3(-4) [6.7(-5)]	7.5(-4) [6.7(-5)]	7.5(-4) [6.7(-5)]	7.5(-4) [6.7(-5)]	7.5(-4) [6.7(-5)]	7.5(-4) [6.7(-5)]	7.5(-4) [6.7(-5)]
$^{239,240}Pu$	—	5.1(-4) [1.6(-4)]	4.0(-4) [1.2(-4)]	—	5.8(-3) [2.1(-3)]	4.3(-3) [1.5(-3)]	—	1.7(-2) [6.0(-3)]	1.2(-2) [4.2(-3)]	—	—	—
TOTAL	4.2	4.9	4.2	12	15	12	17	21	17	21	25	21

*W.B. = Whole Body

[σ in brackets]

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Table 27. Integral 10 year Dose - Rem

Living Pattern	Inhalation Lung	Bone	Liver	External W.B.*, Bone marrow, Liver	Marine W.B.	Bone marrow	Liver	Terrestrial W.B.	Bone marrow	Liver	Water W.B.	Bone marrow	Liver	Total W.B.	Bon marr
Case 1	6.8(-3)	5.7(-4)	4.5(-4)	1.14	2.3(-2)	7.4(-2)	2.3(-2)	0.67	1.0	0.67	1.2(-2)	7.7(-2)	1.2(-2)	1.8	2.3
Case 2	4.6(-2)	3.9(-3)	3.1(-3)	1.72	2.3(-2)	7.4(-2)	2.3(-2)	4.2	4.9	4.2	7.5(-4)	3.8(-3)	7.5(-4)	6.0	6.7
Case 3	4.6(-2)	3.9(-3)	3.1(-3)	1.66	2.3(-2)	7.4(-2)	2.3(-2)	5.1	6.4	5.1	7.5(-4)	3.8(-3)	7.5(-4)	6.8	8.1
Case 4	4.6(-2)	3.9(-3)	3.1(-3)	1.95	2.3(-2)	7.4(-2)	2.3(-2)	4.2	4.9	4.2	7.5(-4)	3.8(-3)	7.5(-4)	6.2	7.0
Case 5	4.6(-2)	3.9(-3)	3.1(-3)	2.40	2.3(-2)	7.4(-2)	2.3(-2)	5.1	6.4	5.1	7.5(-4)	3.8(-3)	7.5(-4)	7.5	8.8
Case 6	4.6(-2)	3.9(-3)	3.1(-3)	2.40	2.3(-2)	7.4(-2)	2.3(-2)	7.6	11	7.6	7.5(-4)	3.8(-3)	7.5(-4)	10	14

*W.B. = Whole Body

Table 28. Integral 30 year Dose - Rem

Living Pattern	Inhalation Lung	Bone	Liver	External W.B.*, Bone marrow, Liver	Marine W.B.	Bone marrow	Liver	Terrestrial W.B.	Bone marrow	Liver	Water (cistern) W.B.	Bone marrow	Liver	Total W.B.	Bone marrow
Case 1	2.4(-2)	7.8(-3)	5.8(-3)	2.9	5.0(-2)	0.20	5.3(-2)	2.0	3.3	2.0	2.9(-2)	2.2(-1)	2.9(-2)	5.0	6.6
Case 2	0.16	5.3(-2)	3.9(-2)	4.3	5.0(-2)	0.20	5.3(-2)	12	15	12	1.9(-3)	1.1(-2)	1.9(-3)	17	19
Case 3	0.16	5.3(-2)	3.9(-2)	4.1	5.0(-2)	0.20	5.3(-2)	14	18	14	1.9(-3)	1.1(-2)	1.9(-3)	19	23
Case 4	0.16	5.3(-2)	3.9(-2)	4.8	5.0(-2)	0.20	5.3(-2)	12	15	12	1.9(-3)	1.1(-2)	1.9(-3)	17	20
Case 5	0.16	5.3(-2)	3.9(-2)	5.9	5.0(-2)	0.20	5.3(-2)	14	18	14	1.9(-3)	1.1(-2)	1.9(-3)	20	25
Case 6	0.16	5.3(-2)	3.9(-2)	5.9	5.0(-2)	0.20	5.3(-2)	23	37	23	1.9(-3)	1.1(-2)	1.9(-3)	29	43

*W.B. = Whole Body

Table 29. Integral 50 year Dose - Rem

Living Pattern	Inhalation Lung	Inhalation Bone	Inhalation Liver	External W.B.*, Bone marrow, Liver	Marine W.B.	Marine Bone marrow	Marine Liver	Terrestrial W.B.	Terrestrial Bone marrow	Terrestrial Liver	Water W.B.	Water Bone marrow	Water Liver	Total W.B.	Total Bone marr
Case 1	4.1(-2)	2.3(-2)	1.6(-2)	4.2	6.6(-2)	0.29	7.4(-2)	2.8	4.7	2.8	4.0(-2)	0.32	4.0(-2)	7.1	9.5
Case 2	0.28	0.16	0.11	6.1	6.6(-2)	0.29	7.4(-2)	17	21	17	2.6(-3)	1.6(-2)	2.7(-3)	23	27
Case 3	0.28	0.16	0.11	5.9	6.6(-2)	0.29	7.4(-2)	20	26	20	2.6(-3)	1.6(-2)	2.7(-3)	26	32
Case 4	0.28	0.16	0.11	6.8	6.6(-2)	0.29	7.4(-2)	17	21	17	2.6(-3)	1.6(-2)	2.7(-3)	24	28
Case 5	0.28	0.16	0.11	8.3	6.6(-2)	0.29	7.4(-2)	20	26	20	2.6(-3)	1.6(-2)	2.7(-3)	29	33
Case 6	0.28	0.16	0.11	8.3	6.6(-2)	0.29	7.4(-2)	33	53	33	2.6(-3)	1.6(-2)	2.7(-3)	41	62

*W.B. = Whole Body

Table 30. Integral 70 year Dose - Rem

Living Pattern	Inhalation Lung	Inhalation Bone	Inhalation Liver	External W.B.*, Bone marrow, Liver	Marine W.B.	Marine Bone marrow	Marine Liver	Terrestrial W.B.	Terrestrial Bone marrow	Terrestrial Liver	Water W.B.	Water Bone marrow	Water Liver	Total W.B.	Total Bo marr
Case 1	5.8(-2)	4.6(-2)	3.0(-2)	5.20	7.6(-2)	0.35	9.0(-2)	3.3	6.6	3.3	4.7(-2)	3.7(-1)	4.7(-2)	6.6	13
Case 2	0.39	0.31	0.20	7.38	7.6(-2)	0.35	9.0(-2)	21	25	21	3.0(-3)	1.9(-2)	3.2(-3)	28	33
Case 3	0.39	0.31	0.20	7.13	7.6(-2)	0.35	9.0(-2)	24	31	24	3.0(-3)	1.9(-2)	3.2(-3)	31	38
Case 4	0.39	0.31	0.20	8.24	7.6(-2)	0.35	9.0(-2)	21	25	21	3.0(-3)	1.9(-2)	3.2(-3)	29	34
Case 5	0.39	0.31	0.20	9.94	7.6(-2)	0.35	9.0(-2)	24	31	24	3.0(-3)	1.9(-2)	3.2(-3)	34	41
Case 6	0.39	0.31	0.20	9.94	7.6(-2)	0.35	9.0(-2)	39	63	39	3.0(-3)	1.9(-2)	3.2(-3)	49	74

*W.B. = Whole Body

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Table 31

Percent of Total 30 year Integral Bone Marrow Dose

Living Pattern	Inhalation	External	Marine	Terrestrial	Water
Case 1	0.12	44	3.0	50	3.4
Case 2	0.27	22	1.0	76	0.05
Case 3	0.23	18	0.88	81	0.05
Case 4	0.27	24	1.0	74	0.06
Case 5	0.22	24	0.82	75	0.04
Case 6	0.12	14	0.47	86	0.03

Percent of Total 30 year Integral Whole Body Dose

Living Pattern	Inhalation	External	Marine	Terrestrial	Water
Case 1	-	58	1.0	40	0.58
Case 2	-	26	0.30	74	0.01
Case 3	-	22	0.27	77	0.01
Case 4	-	28	0.29	71	0.01
Case 5	-	29	0.25	71	0.009
Case 6	-	20	0.17	79	0.006

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Table 32. Summation of All Exposure Pathways

	Integral 30 year Dose-Rem		Integral 50 year Dose-Rem	
Living Pattern	Whole Body	Bone Marrow	Whole Body	Bone Marrow
Case 1	5.0	6.6	7.1	9.5
Case 2	17	19	23	27
Case 3	19	23	26	32
Case 4	17	20	24	28
Case 5	20	25	29	35
Case 6	29	43	41	62

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Table 33. 30 Year Integral Dose Comparisons of Living Patterns for Bikini and Enewetak Atolls

Living Patterns and Location	Whole Body Rem	Bone Marrow Rem	W.B. & Bone Marrow Federal Guidelines† Rem
Bikini Case 1 - Eneu Island	5.0	6.6	15
Bikini Case 6 - Bikini Island	29	43	15
Enewetak Case 3* - Enjebi Island	11	16	15
Enewetak Case 1* - Southern Islands	1.0	1.2	15
United States Background Radiation**	3.0	3.0	15

* See Enewetak Radiological Survey - Volume 1, 1973

† Federal Guide of 0.5 rem/yr times 30 years

** Based upon an annual external background dose of 100 /yr at sea level.

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